Environmental Requirements and Verification for NASA's Planned Europa Clipper Mission

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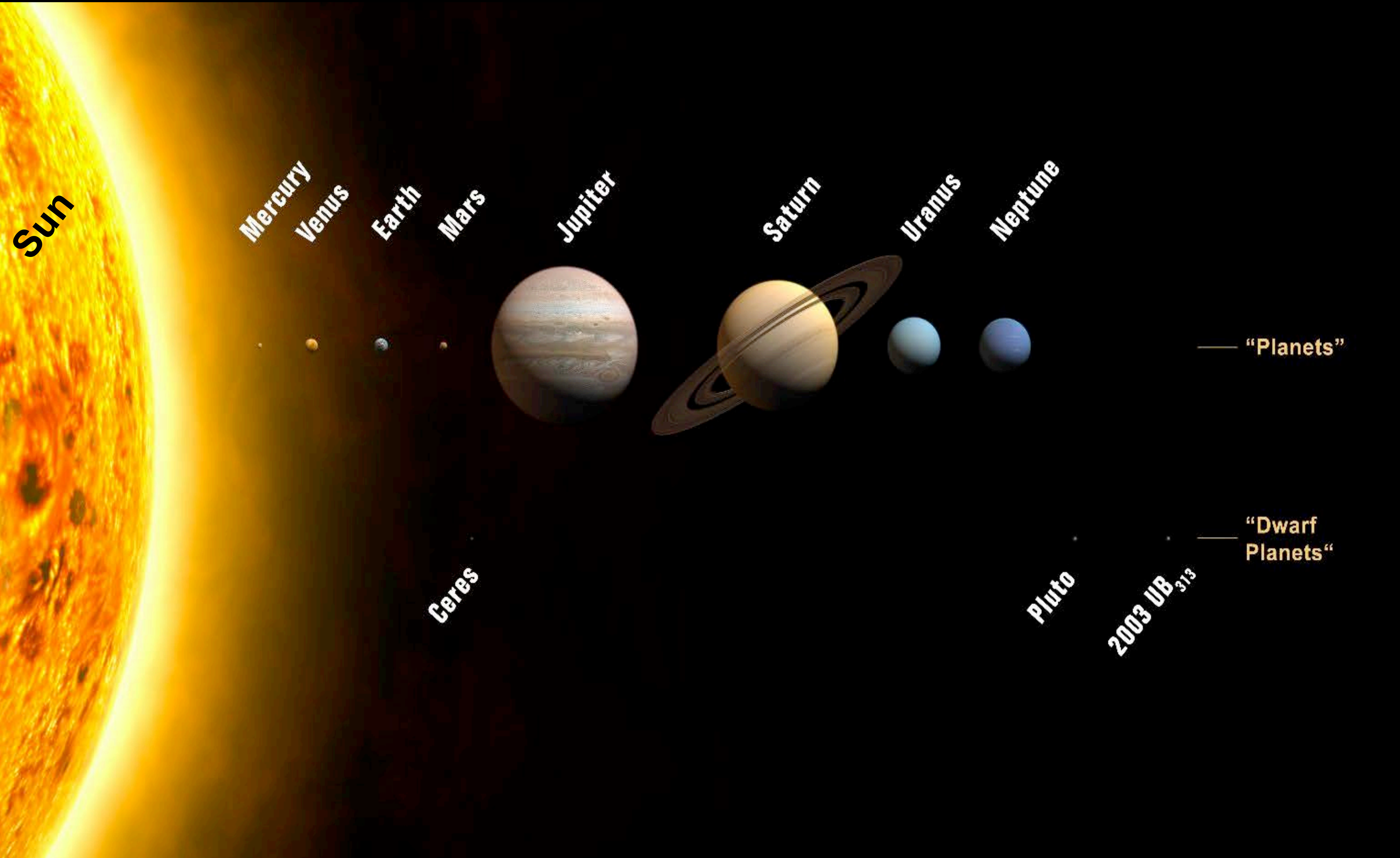
Jet Propulsion Laboratory
California Institute of Technology

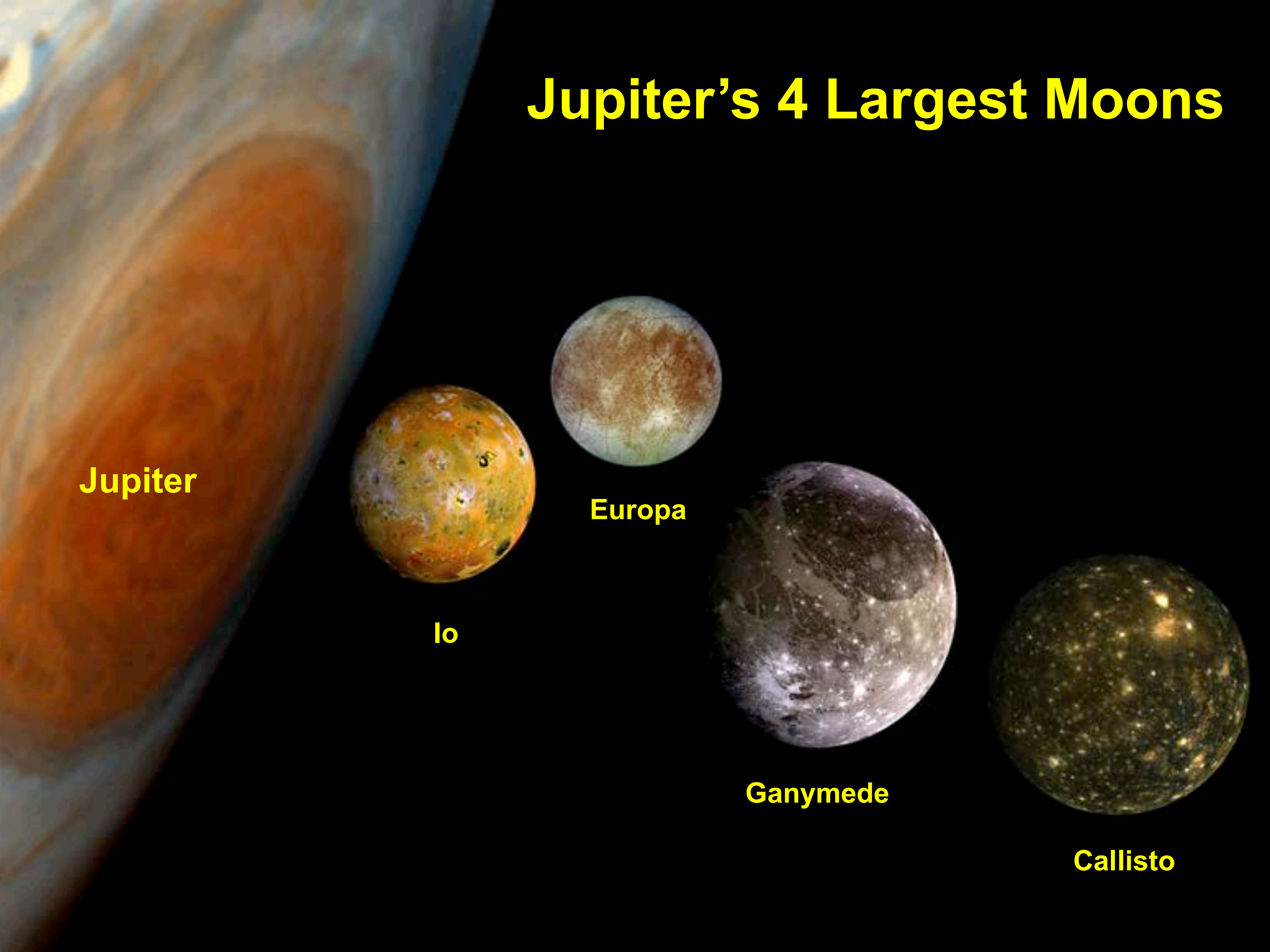
Agenda

- **Jupiter and Europa**
  - **Why Explore Jupiter's moon Europa**
- **Mission and Flight Systems**
  - **Mission Objective**
  - **Spacecraft and Instruments Description**
- **Environmental Requirements and Verification Program**
  - **Challenging Environments**
  - **Environmental Verification (Subsystems and Spacecraft)**
- **Conclusions**

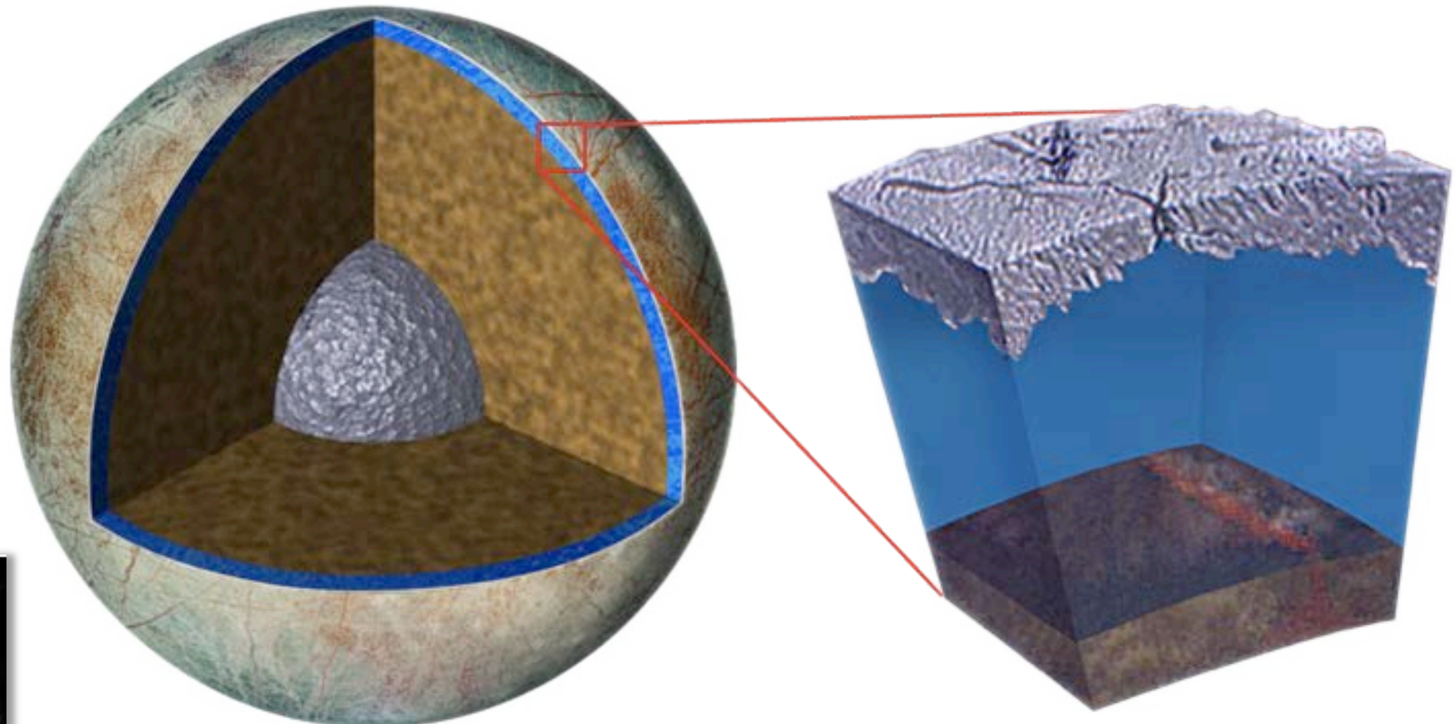
Jupiter


Sun
Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptune
"Planets"
Ceres
Pluto
2003 UB313
"Dwarf Planets"

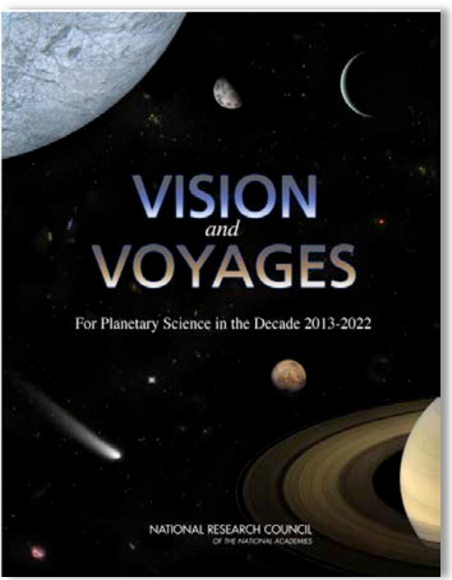
Jupiter’s 4 Largest Moons



Why Europa



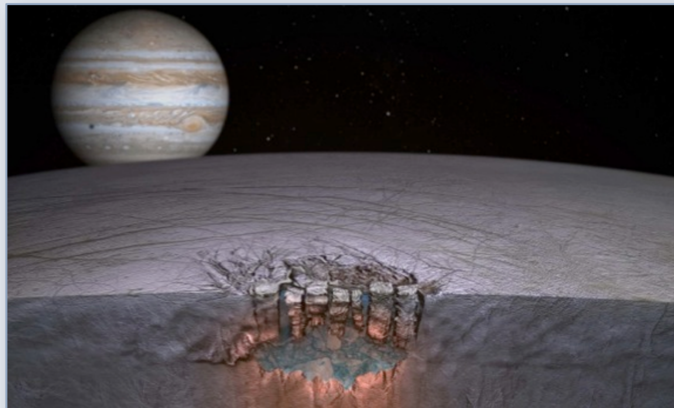
8 March 2015



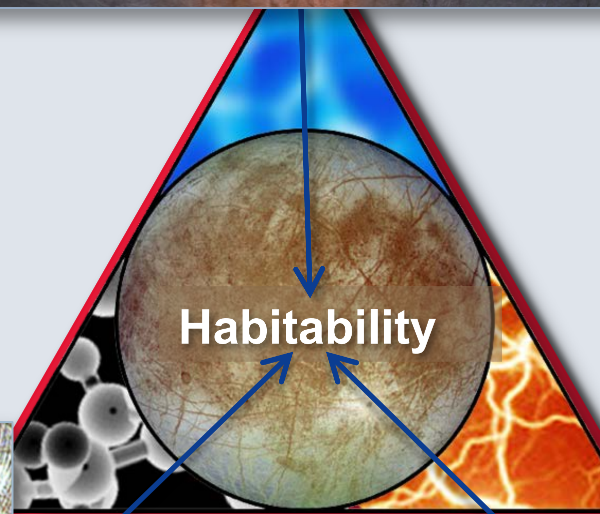
"Europa, with its probable vast subsurface ocean sandwiched between a potentially active silicate interior and a highly dynamic surface ice shell, offers one of the most promising extraterrestrial habitable environments, and a plausible model for habitable environments beyond our solar system"

The Planetary Decadal Survey

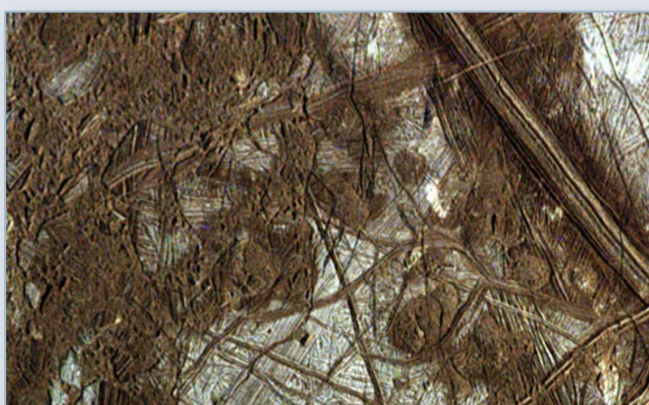
Ingredients for Life



Water: ocean and lakes hidden by Europa's shell of ice?



Essential Elements: O_2, H_2, S, C, organics?



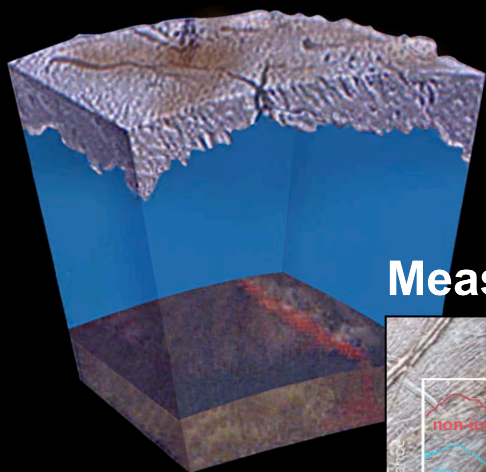
Chemical Energy: oxidants provide energy for metabolism?

Stability:
"simmering" for 4B yrs

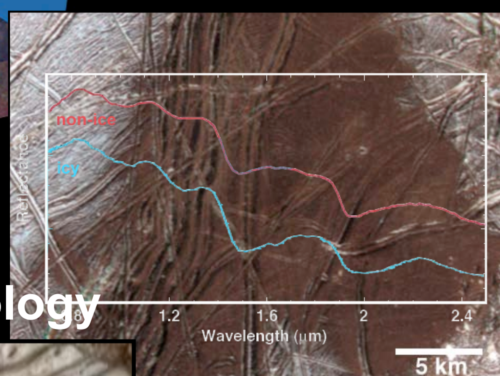
Europa Clipper Mission Objective:

- Explore Europa to investigate its habitability.

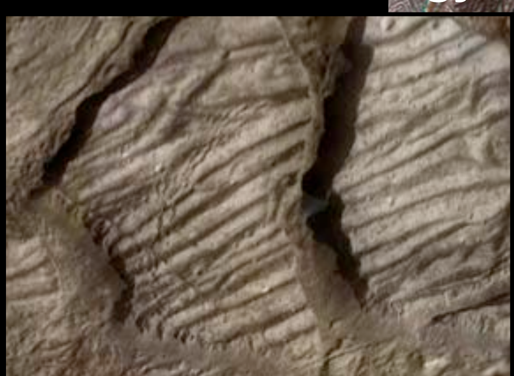
Characterize Ice Shell and Subsurface Water



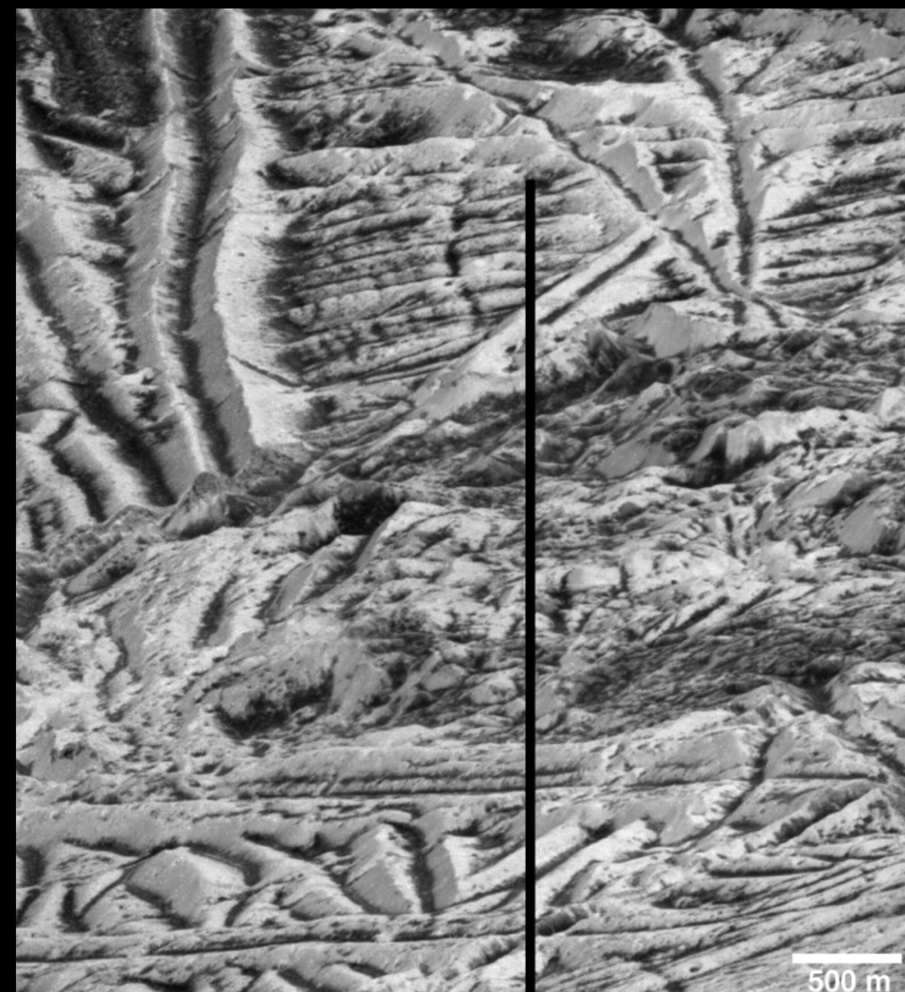
Measure Composition

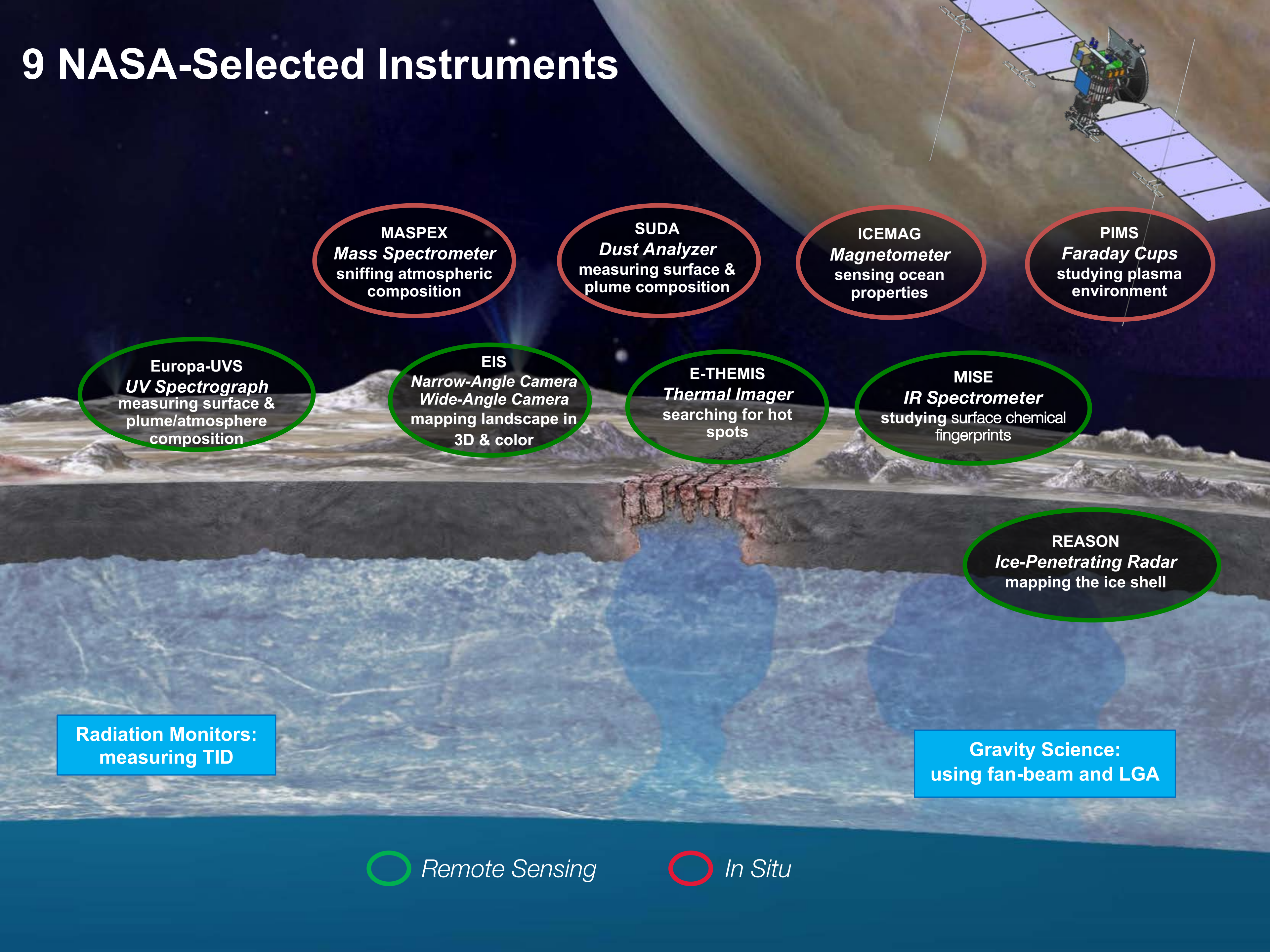


Understand Geology

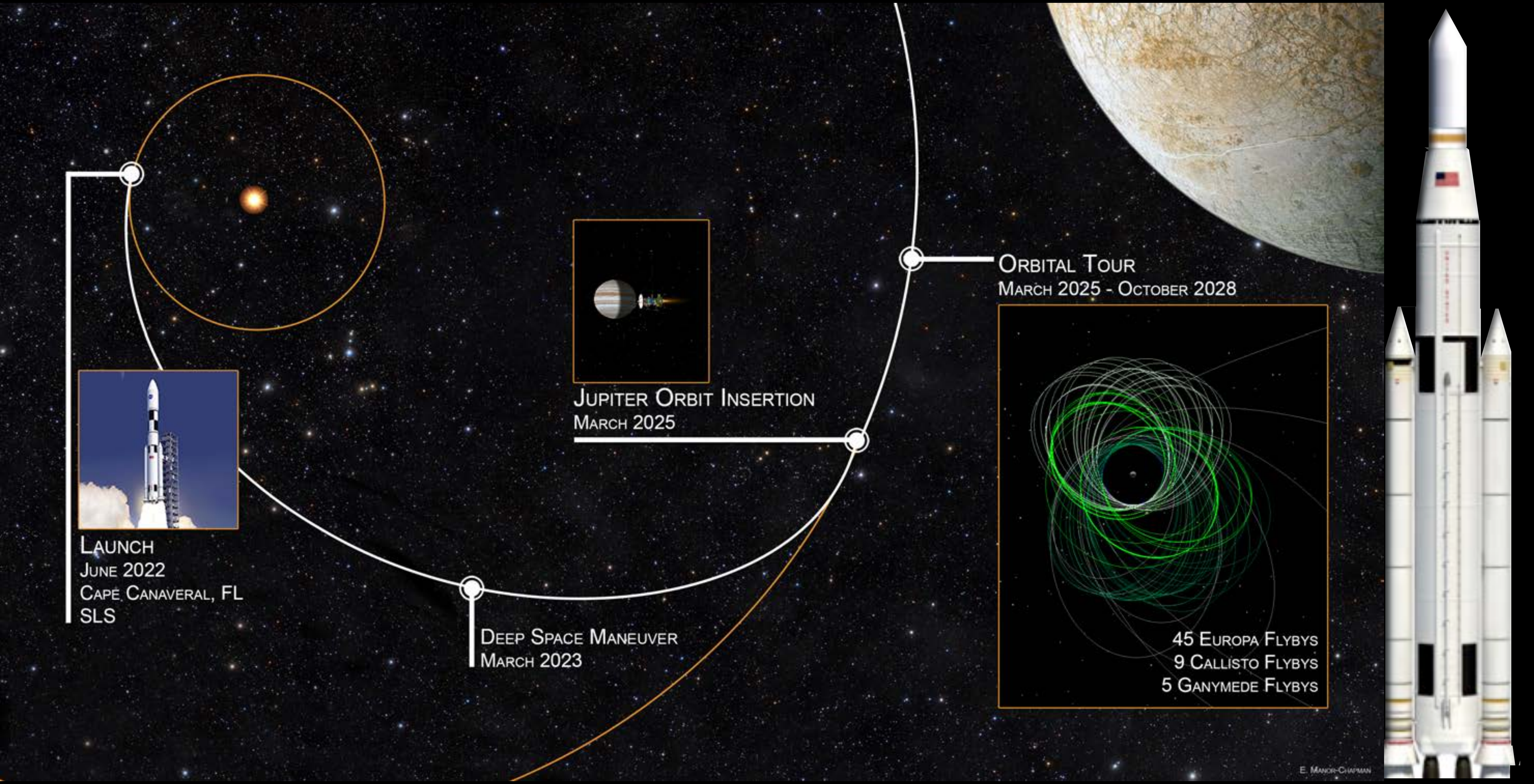


Reconnaissance



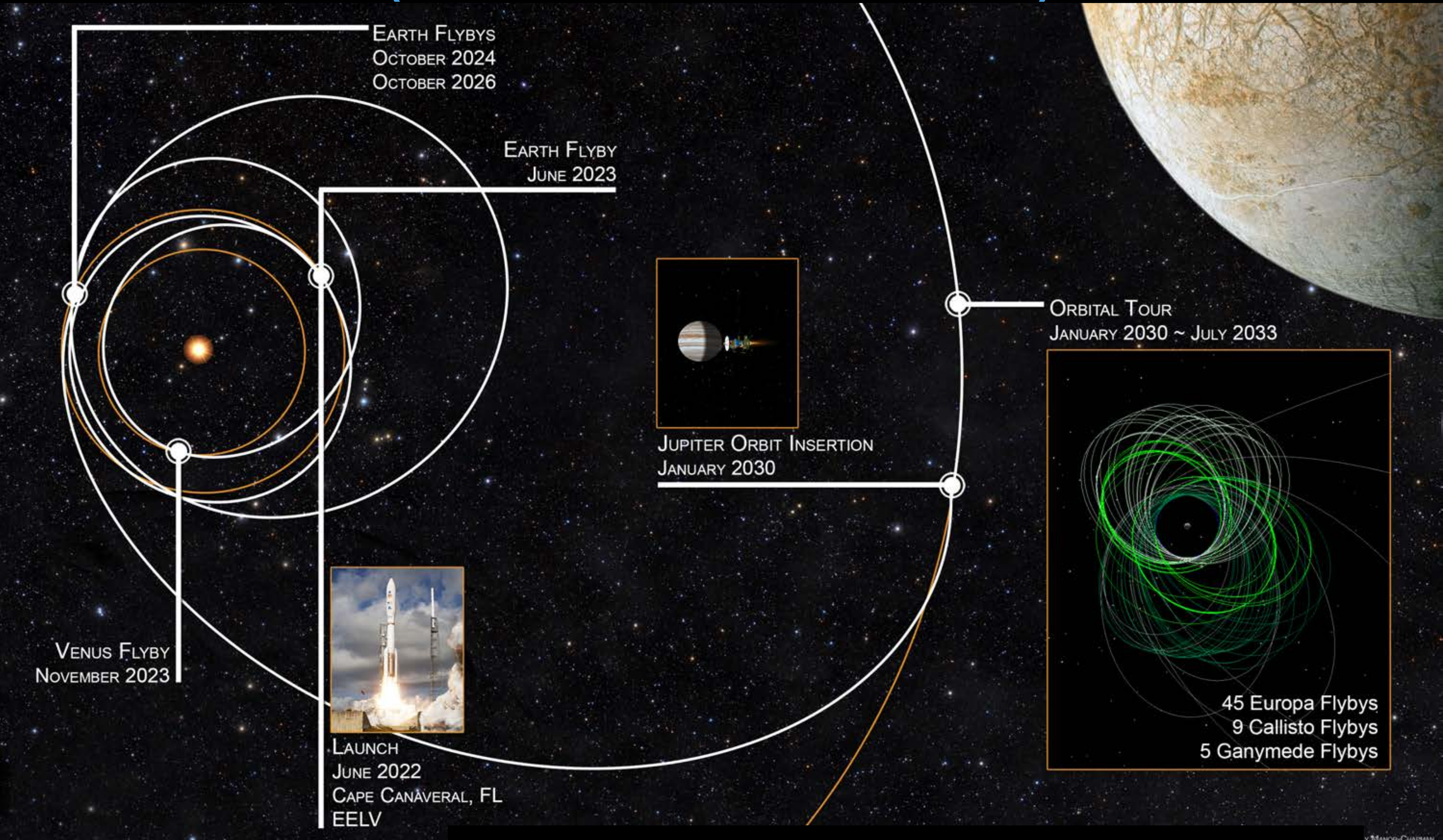

9 NASA-Selected Instruments
MASPEX
Mass Spectrometer
sniffing atmospheric composition
SUDA
Dust Analyzer
measuring surface & plume composition
ICEMAG
Magnetometer
sensing ocean properties
PIMS
Faraday Cups
studying plasma environment
Europa-UVS
UV Spectrograph
measuring surface & plume/atmosphere composition
EIS
Narrow-Angle Camera
Wide-Angle Camera
mapping landscape in 3D & color
E-THEMIS
Thermal Imager
searching for hot spots
MISE
IR Spectrometer
studying surface chemical fingerprints
REASON
Ice-Penetrating Radar
mapping the ice shell
Radiation Monitors: measuring TID
Gravity Science: using fan-beam and LGA
Remote Sensing
In Situ

Direct-to-Jupiter Trajectory (SLS Launch Option)



- 21 Day launch period opens June 2022.
- Arrive Jovian System March 2025 (2.7 Years).
- 3.5 year Jovian tour after Jupiter orbit insertion.
- 45 Europa flybys.

Gravity-Assist EVEEGA Interplanetary Trajectory (Delta-IVH or other EELV)



- 21 Day launch period opens June 2022.
- Earth/Venus/Earth/Earth Gravity Assist (EVEEGA) trajectory.
- Arrive Jovian System January, 2030 (7.5 Years).

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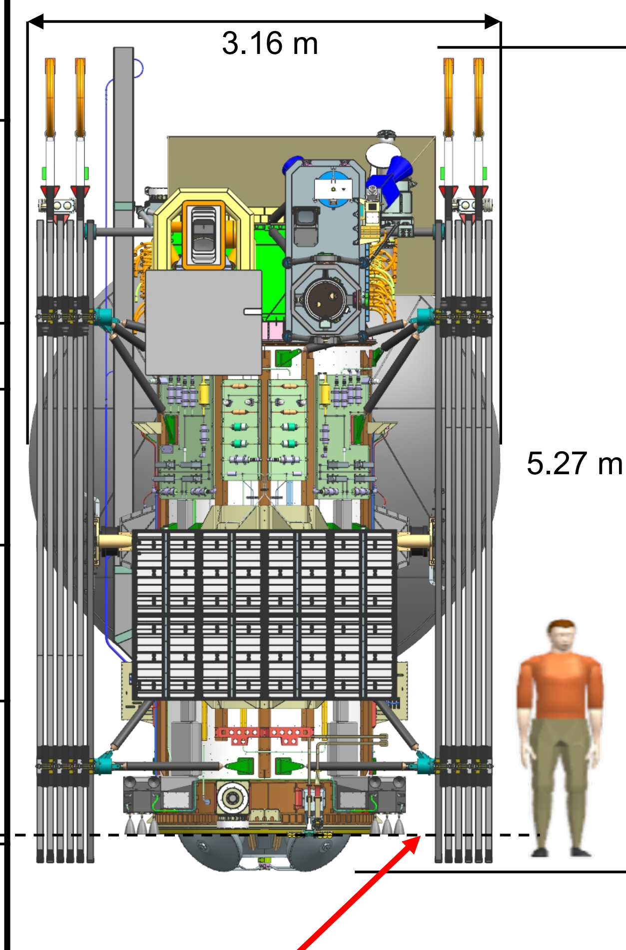
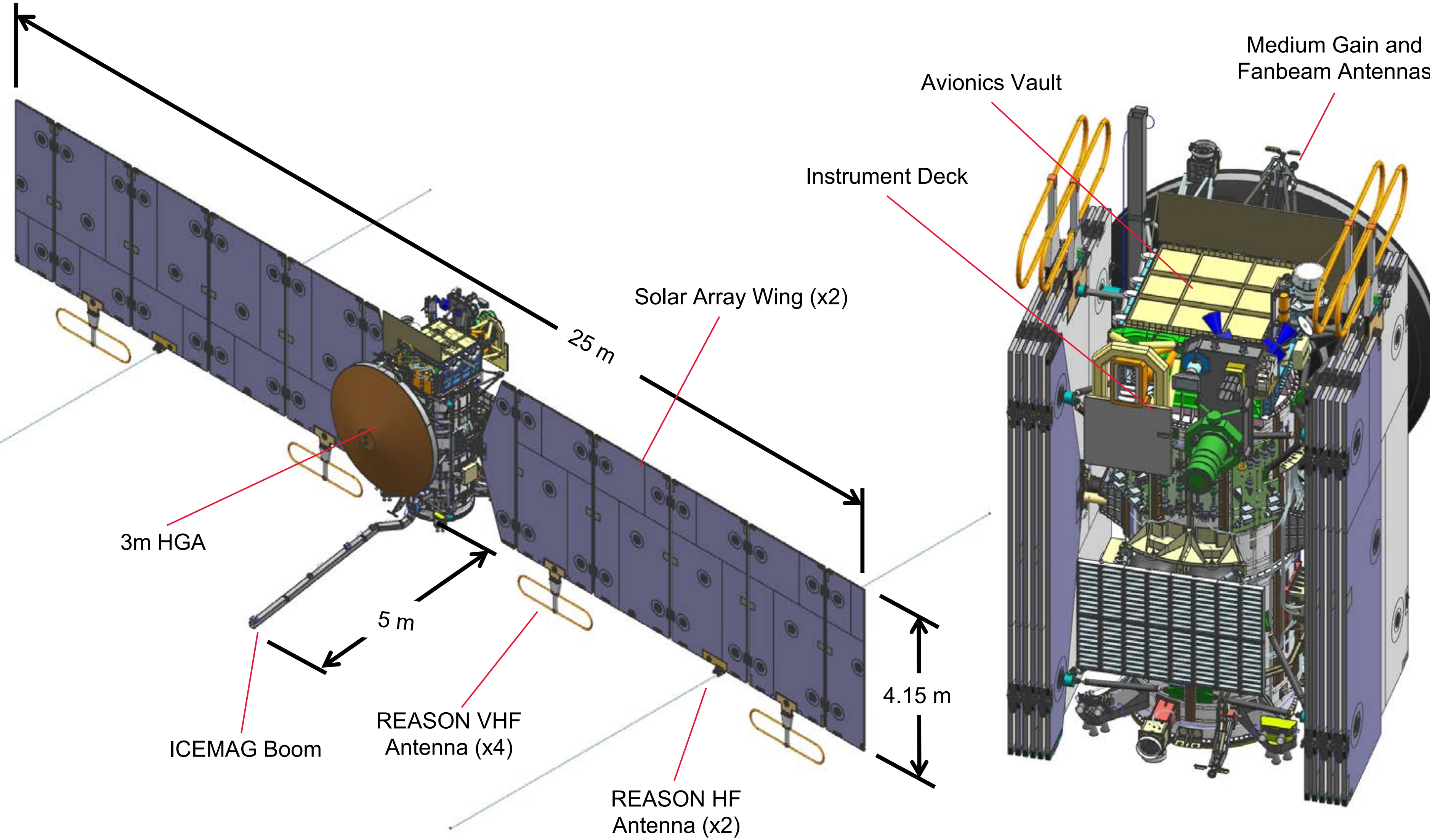
Spacecraft Design Overview

Power	• Solar-powered mission: 86 m^2 Solar Array generating 650 W (EOM) • 339 Ah (EOM) Battery for eclipses, TCM, & flybys • Single axis gimbaled arrays
Propulsion	• Bipropellant MMH/NTO/MON-3 propulsion subsystem • 1669 m/s; 2750kg fuel (MEV) • 25 N DST-13X main engine and RCS engines (24) • 1.17 m (49”) diameter tanks
Avionics	• RAD750 flight computer and 512 Gb data storage
Telecom	• X-band: Uplink & 20W Downlink • Ka-band: 35 W Downlink (85 kbps @ max range) • 3-m HGA, MGA, fan beam (3) and LGA (2)
Control	• 3-axis: Reaction wheels(4), RCS engines (cruise) • Pointing Ka 1 mrad, UVS 0.7 mrad • Star trackers(2), IMU(2), sun sensors(6)
Thermal	• Active thermal control with fluid pump loop, MLI, heaters, radiator with louvers • Avionics heat reclamation – minimizes electrical heaters
Mechanical	• 5.27 m tall by 3.16 m wide by 4.15 m deep • 6001 Kg launch/wet mass • Non-load bearing tanks, nadir platform • Deploy solar array and mag boom • Vault significantly reduces total dose to electronics



Deployed & Stowed Configurations



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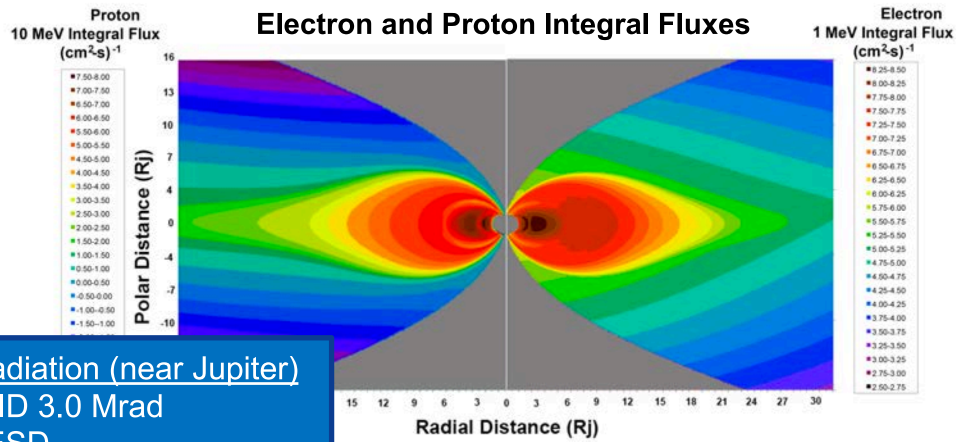
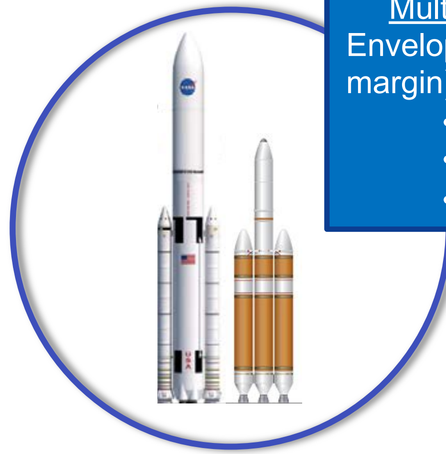
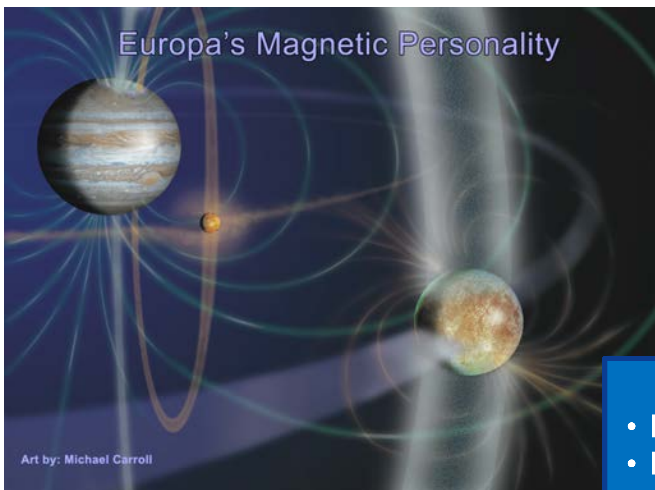
Environmental Challenges



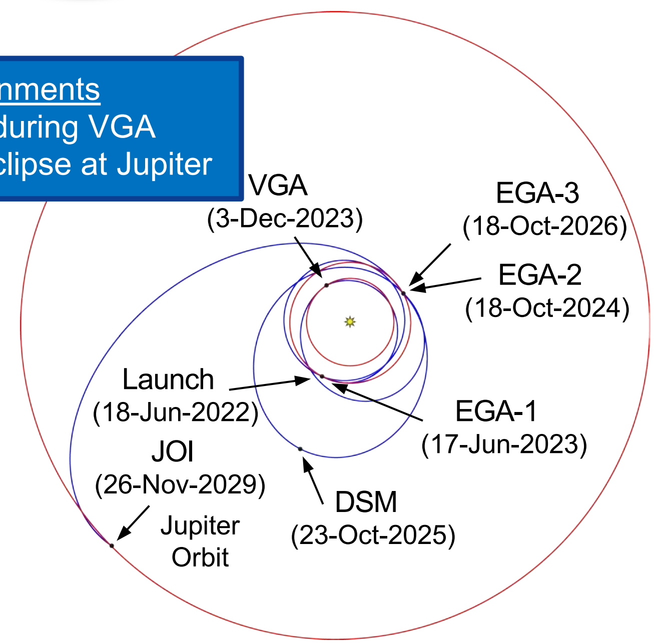
Radiation (near Jupiter)
- TID 3.0 Mrad
- iESD
- Flux-Electronics & Matl



Multiple Launch Vehicles
Envelop worst-case env (+ margin) for all potential LVs:
- Acoustic
- Vibration
- Shock



Thermal Environments
- Hot extreme: 0.65AU during VGA
- Cold extreme: 9.2hr eclipse at Jupiter



EMC/EMI/Magnetics
- Radar 9 and 60 MHz interference
- E-field for low-energy plasma particles
- Magnetic cleanliness for Magnetometer

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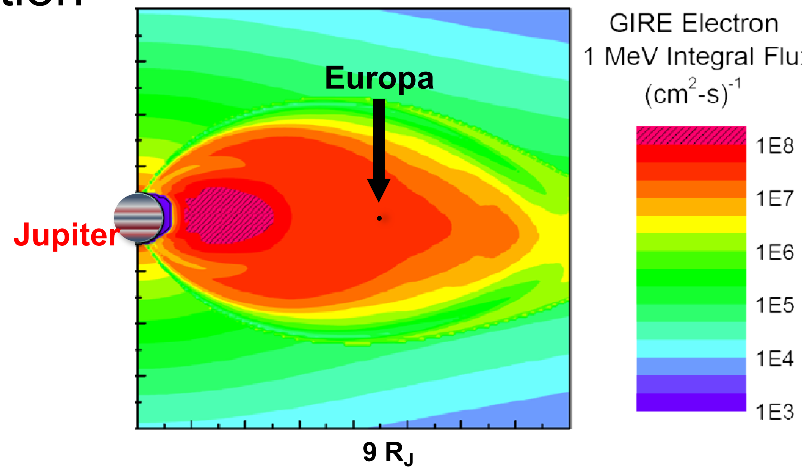
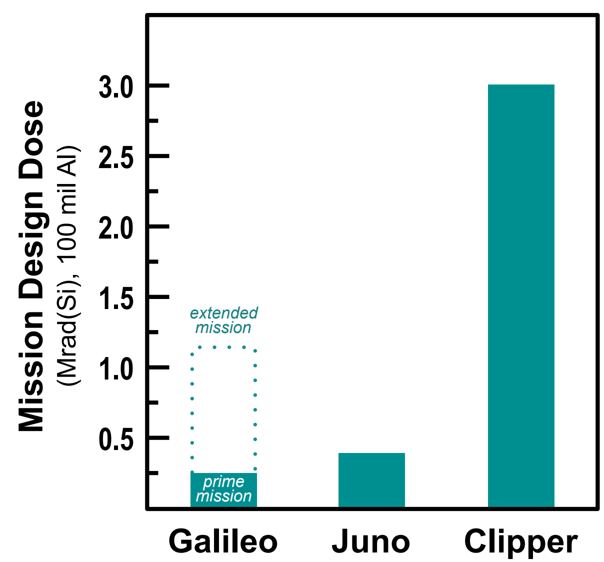
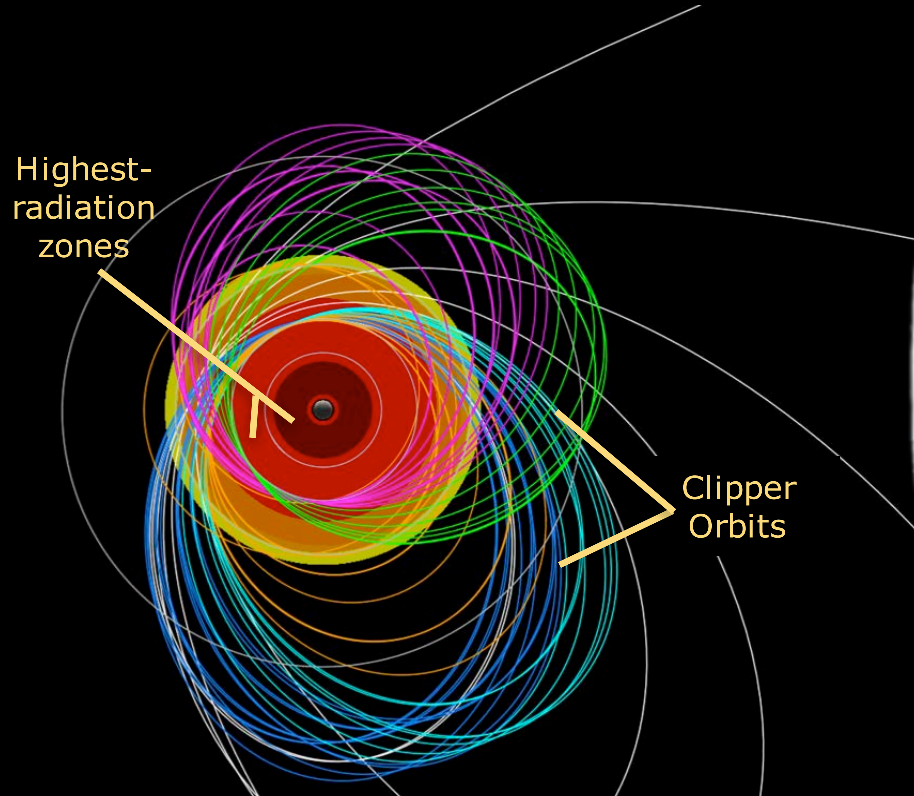
Radiation Environment

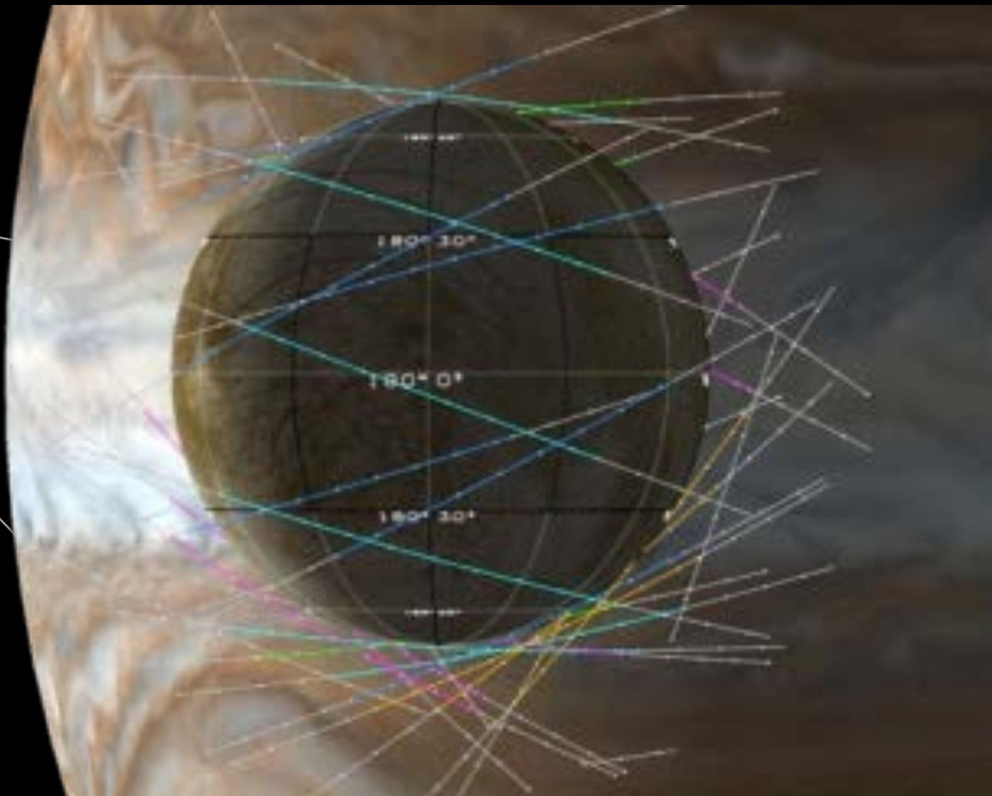
- Europa lies well within the Jovian radiation and plasma environment.
- Total mission design dose.
  - 3 Mrad (100 mil Al).
  - Higher than previous missions.
- Employ strategies to mitigate radiation effects.
  - Minimize radiation exposure through innovative trajectory design.
  - Maintain conservative radiation design margin.
    - RDF = 2.
  - Shield electronics in “Radiation Vault”.
    - $\leq$150 Krad.
  - Use rad-hard EEE parts inside vault.
    - $\geq$300 Krad.

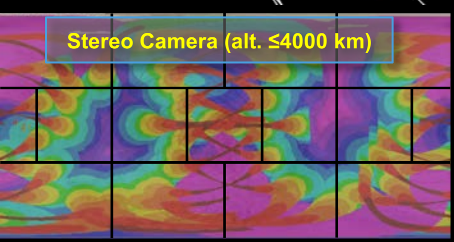


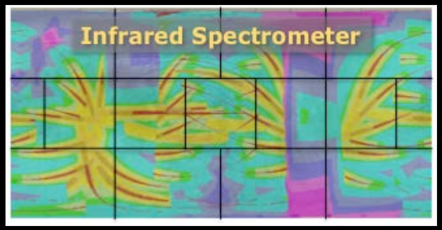


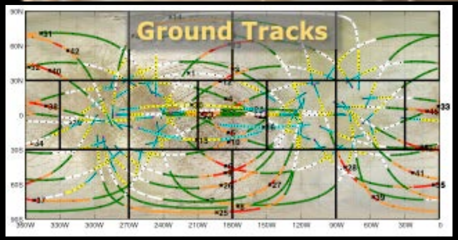
Innovative Trajectory Design

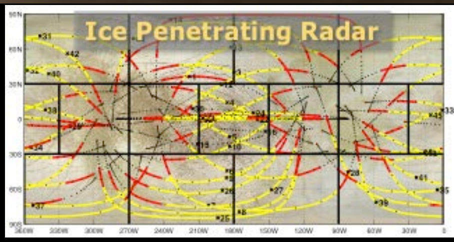












- Design Europa flyby trajectories to be highly-elliptical orbits to limit time spent in the high Jovian radiation environment.
- Criss crosses Europa Surface.
- The closest-approach is as low as 25 km.

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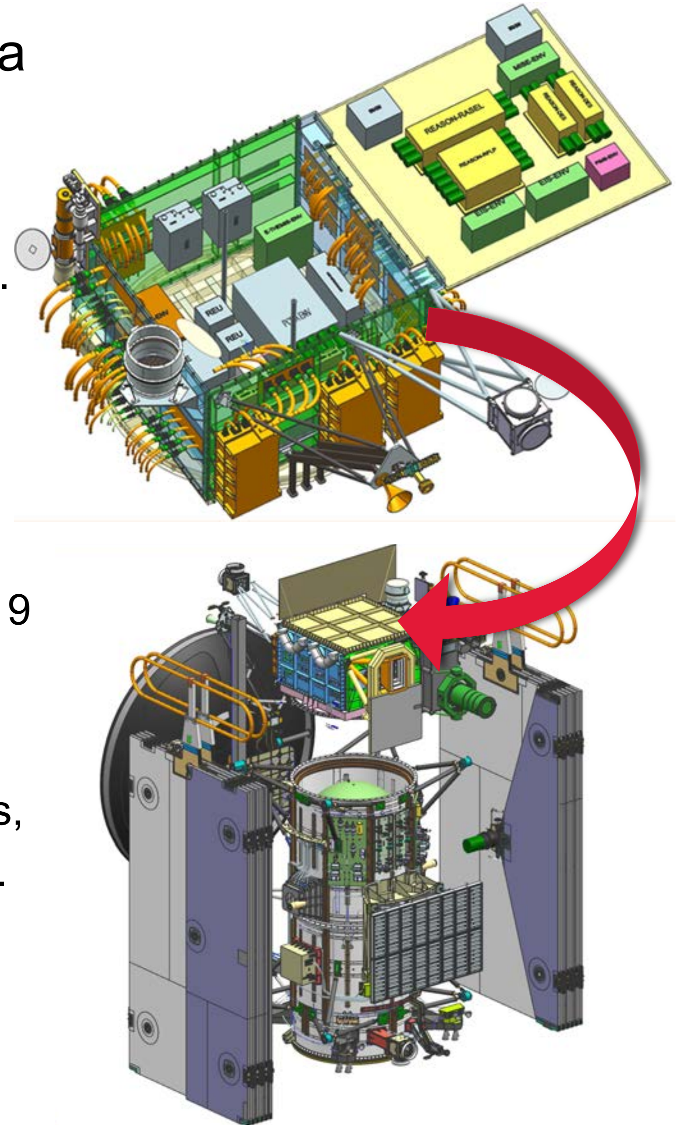
Radiation-Shielded Vault Design

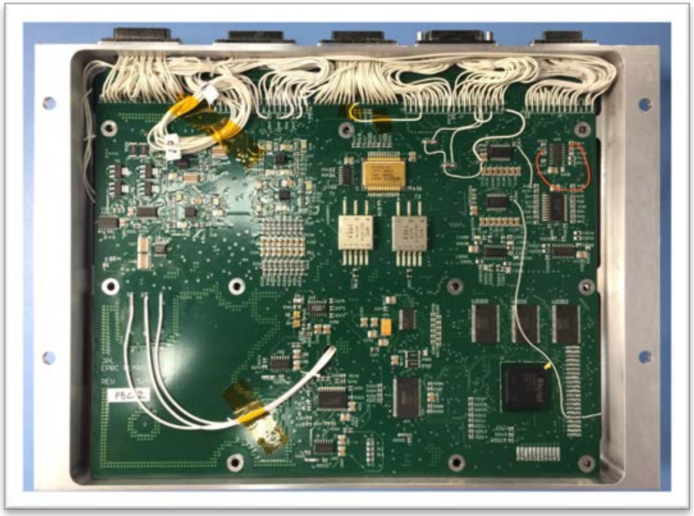
- Place all control electronics in a shielded aluminum vault.
- Avionics vault description:
  - Dimensions:1.18mx1.15mx0.88m.
  - Wall thickness 10.6mm, Al.
  - Total vault mass = 216.4 kg.
- Performed radiation transport analyses.
  - Using NOVICE analysis tool, with 9 detectors/box.
- Analyses results.
  - <150 Krad(Si) for most electronics, with 10.6 mm vault wall thickness.
- To achieve 100% compliance.
  - Use thicker walls, or
  - Localized shielding.



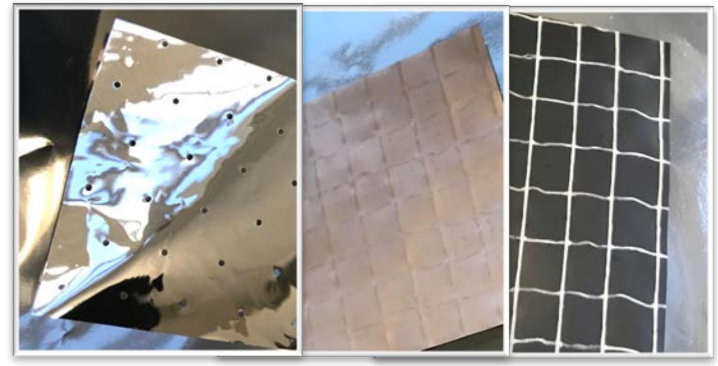
Europa Clipper	Vault (10.6 mm aluminum panels, with hollow decks & solar panels)
E-box Configuration	20% soup in box with 100 mil wall
Electronics Assembly	**Radiation TID (Rad, Si)**
MASPEX	1.20E+05
Integrated Pump	1.13E+05
PIMS	1.45E+05
EIS 1	1.82E+05
EIS 2	1.74E+05
CDH 1	1.24E+05
CDH 2	1.23E+05
E-THEMIS	1.35E+05
PCDA	1.11E+05
Radiation Monitor	9.20E+04
MISE	1.38E+05
SUDA	8.46E+04
ICEMAG	1.19E+05
REU 1	9.08E+04
REU 2	1.10E+05
CryoCooler	1.19E+05
REASON RASEL	1.26E+05
REASON RFLP	1.18E+05
REASON DES #1	1.27E+05
REASON DES #2	1.41E+05
SRU 1	1.40E+05
SRU 2	1.33E+05
SIRU 1	1.67E+05
SIRU 2	1.18E+05
RW 1	1.29E+05
RW 2	1.38E+05
RW 3	1.14E+05
RW 4	1.26E+05
AVERAGE	**1.27E+05**

EEE Parts Radiation Qualification

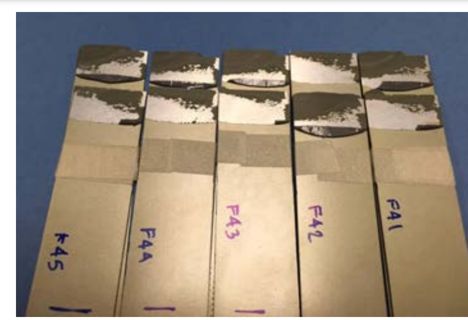
- All EEE parts need to meet high-radiation environment and long-term reliability.
- Performed extensive radiation testing of all required electronics part types that would potentially survive 300 Krad(Si) TID (HDR & LDR).
- Qualified parts that meet the Parts Plan requirements are placed in the **Preferred Parts Selection List (PPSL)**.
  - Examples: commercial NAND Flash memories, buck converters, linear devices, DDR2 memory, opto-couplers, FPGAs, DACs, temperature sensors, etc.
- Subsystems and instruments can select from list for their electronics design without further qualification.
  - Only RLAT (Radiation Lot Acceptance Test) is required.
- If not on the list, additional radiation qualifications are required.



Materials Qualification

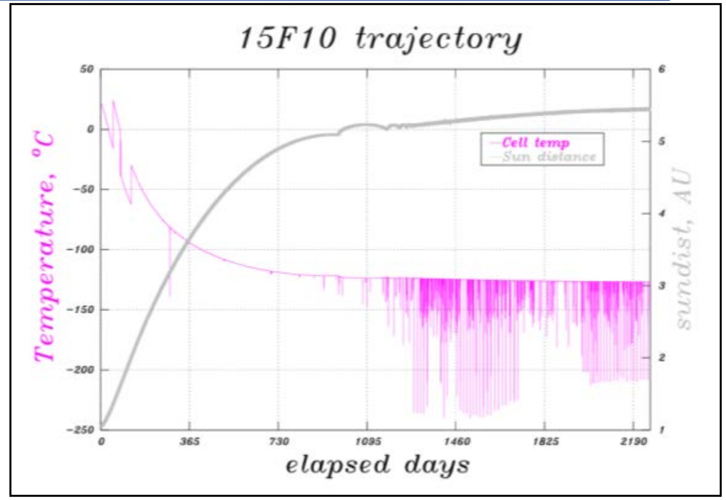


- Materials unshielded or partially-shielded can experience 100's Mrad(Si) or even Grads(Si) TID levels.
- Some materials can degrade or fail in these high-radiation environments.
- Radiation tested an extensive set of materials.
  - Some tested in conjunction with thermal cycling at hot and cold extremes.
- The acceptable materials are placed in a **Preferred Materials and Processes Selection List (PMPSL)**.
  - Examples: wire harnesses, multilayer insulations, heaters, platinum resistance thermometers, solar array adhesives, wire spot bonding products, etc.
- Subsystems and instruments can select from list for their design applications without further qualification.
- If not on the list, additional qualifications are required.



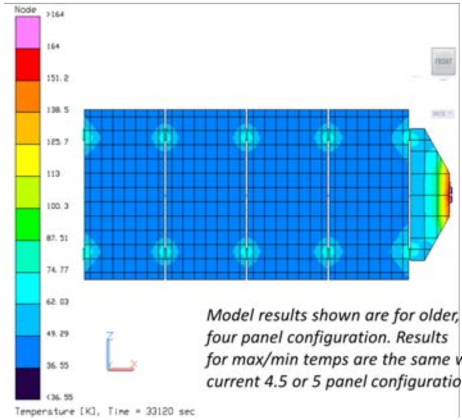
Thermal Extreme Environments

- Hot extreme environment.
  - Occurs near Venus during VGA (Venus gravity assist).
  - Closest solar approach: 0.65 AU.
  - Solar flux of 3237 W/m^2 (c.f. the mean solar flux near Earth is 1367.5 W/m^2).
  - E.g. The predicted worst-case hot temperature is 175^{o}C for High Gain Antenna.



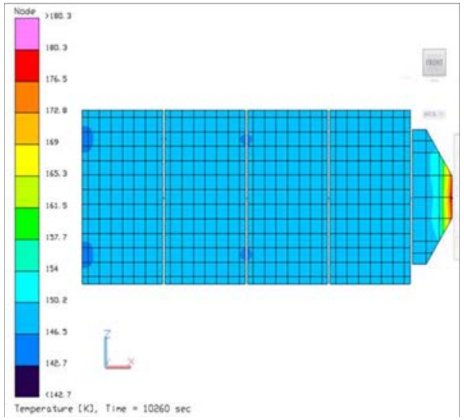
- Cold extreme environment.
  - Occurs during Europa science orbits.
  - Furthest science orbit: 5.6 AU.
  - Solar flux of 43.6 W/m^2.
  - Worst-case extreme is during 9.2-hour Jupiter eclipse.
  - E.g. Predicted worst-case cold temperature, directly exposed to space, without temperature control, and non-operating, is -240^{o}C (for the deployed REASON antennas).

9.2 hr eclipse temperatures



Model results shown are for older, four panel configuration. Results for max/min temps are the same with current 4.5 or 5 panel configuration.

Jupiter orbit steady state temperatures



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Thermal Vacuum Testing

- The predicted AFTs and test temperatures are specified in the Temperature Requirements Table (TRT).
  - For both op and non-op temperatures.
- All flight assemblies/subsystems or instruments are required to undergo thermal vacuum test; PF or FA (after Q with an engineering unit).
  - Test to the temperature limits as specified in the TRT, durations, and number of cycles.
- The spacecraft will undergo a thermal balance test.
  - Verify the flight hardware system thermal control design is able to maintain the AFTs, thermal gradients, and thermal stability.

Europa Hardware	Temperature Requirements, °C											
	Allowable Flight				Protoflight/Qual				Flight Acceptance			
	Operational		Nonoperational		Operational		Nonoperational		Operational		Nonoperational	
	min	max	min	max	min	max	min	max	min	max	min	max
Telecom Subsystem												
Fan-beam Antenna	-135	105	-135	105	-150	125	-150	125	-140	110	-140	110
Low Gain Antenna, (LGA)	-135	105	-135	105	-150	125	-150	125	-140	110	-140	110
Mid Gain Antenna, (MGA)	-135	105	-135	105	-150	125	-150	125	-140	110	-140	110
High Gain Antenna, (HGA)	-215	105	-215	105	-230	125	-230	125	-220	110	-220	110
Frontier Radio	-20	50	-20	50	-35	70	-35	70	-25	55	-25	55
Ka-Band Amp High Voltage Power Supply	-15	50	-15	55	-30	70	-30	75	-20	55	-20	60
X-Band Amp High Voltage Power Supply	-15	50	-15	55	-30	70	-30	75	-20	55	-20	60
Ka-Band Amplifier Tube and Electron Gun	-10	65	-20	70	-25	85	-35	90	-15	70	-25	75
X-Band Amplifier Tube and Electron Gun	-10	65	-20	70	-25	85	-35	90	-15	70	-25	75
GNC Subsystem												
Stellar Reference Unit, (SRU), Optical	-25	25	-25	25	-40	45	-40	45	-30	30	-30	30
SRU Baffles	-135	130	-135	130	-150	150	-150	150	-140	135	-140	135
SRU Electronics	-20	50	-20	50	-35	70	-35	70	-25	55	-25	55
Reaction Wheel Drive Electronics	-15	45	-20	50	-30	65	-35	70	-20	50	-25	55
Reaction Wheel Units, (WU)	-15	45	-25	55	-30	65	-40	75	-20	50	-30	60
Coarse Sun Sensor, (CSS) Optics	-90	105	-90	105	-105	125	-105	125	-95	110	-95	110
Power Subsystem												
Prop Module Electronics, (PME)	-20	50	-20	50	-35	70	-35	70	-25	55	-25	55
Power Control and Distribution	-20	50	-20	50	-35	70	-35	70	-25	55	-25	55
Diode Box,	-20	50	-20	50	-35	70	-35	70	-25	55	-25	55
Avionics Subsystem												
Computing Element, (CE)	-20	50	-20	50	-35	70	-35	70	-25	55	-25	55
Remote Engineering Unit, (REU)	-20	50	-20	50	-35	70	-35	70	-25	55	-25	55
Radiation Monitoring Subsystem												
Radiation Monitoring Sensor Assembly	-20	55	-20	55	-35	75	-35	75	-25	60	-25	60
Distributed TID monitors	-20	55	-20	55	-35	75	-35	75	-25	60	-25	60
Thermal Subsystem												
Integrated Pump Assembly, (IPA)	-20	50	-20	50	-35	70	-35	70	-25	55	-25	55
IPA Electronics	-20	50	-20	50	-35	70	-35	70	-25	55	-25	55
Heat Redistribution System, HRS, Fill and Drain Valves	-20	50	-20	50	-35	70	-35	70	-25	55	-25	55
Replacement Heater Block, RHB	-20	50	-20	50	-35	70	-35	70	-25	55	-25	55
HRS Fluid Loop Tubing, wetted. Radiator Service lines	-95	100	-95	100	-105	120	-105	120	-100	105	-100	105
Louver Housing and Frames	-95	35	-95	35	-105	55	-105	55	-100	40	-100	40
Louver Blades, Unstressed (partially open)	-95	380	-95	380	-105	400	-105	400	-100	385	-100	385
Louver Blades, Stressed (fully open or fully closed), shaded	-95	100	-95	100	-105	120	-105	120	-100	105	-100	105
Louver Blades, Stressed (fully open or fully closed), sunlit	-95	100	-95	100	-105	120	-105	120	-100	105	-100	105
Mechanical Subsystem												
Heat Redistribution System, (HRS), Radiator	-95	80	-95	80	-105	100	-105	100	-100	85	-100	85
Nadir Deck Assembly	-60	30	-60	30	-75	50	-75	50	-65	35	-65	35
E-Themis												
Processing and Control Electronics	-20	50	-20	50	-35	70	-35	70	-25	55	-25	55
Telescope and Detector Assembly	0	20	-30	35	-15	40	-45	55	-5	25	-35	40
ICEMAG												
Electronics Box	-10	50	-10	50	-20	70	-25	70	-15	55	-15	55
Flux Gate, (FG), Sensors	-50	50	-120	100	-65	70	-135	120	-55	55	-125	105
Scalar-Vector Helium, (SVH), Sensors	-25	30	-25	70	-40	50	-40	90	-30	35	-30	75
Fiber Cable	-25	60	-25	85	-40	80	-40	105	-30	65	-30	90

Acoustics Environment

- The Maximum Predicted Flight Environment is an envelope of Delta IV H and SLS B1B launch acoustic environments.
- The predicted Qual level is 147.7 dB.
  - Higher than a typical mission, due to the need to maintain compliance with multiple launch vehicles.
- The spacecraft is required to perform an acoustic test at Protoflight level.
  - 147.7 dB for 1 minute.
- Acoustics testing is only required for selected assemblies or subsystems.
  - Hardware with high surface-to-mass ratios.
  - E.g. Solar Arrays (SA) and High Gain Antenna (HGA).

1/3 Octave Band Center Frequency (Hz)	FA Sound Pressure Level (dB ref. 20 μPa) FA: 1 minute	Qual/PF Sound Pressure Level (dB ref. 20 μPa) Qual/PF:2/1 minute)
31.5	129	132
40	134.8	137.8
50	135.4	138.4
63	135.2	138.2
80	134.8	137.8
100	134.6	137.1
125	133.5	136.5
160	133	136
200	133	136
250	133	136
315	133	136
400	131	134
500	129	132
630	126.5	129.5
800	124.5	127.5
1000	122.5	125.5
1250	120.7	123.7
1600	118.3	121.3
2000	116.5	119.5
2500	115	118
3150	113	116
4000	111.5	114.5
5000	109.5	112.5
6300	107.5	110.5
8000	106	109
10000	104	107
Overall	**144.7**	**147.7**

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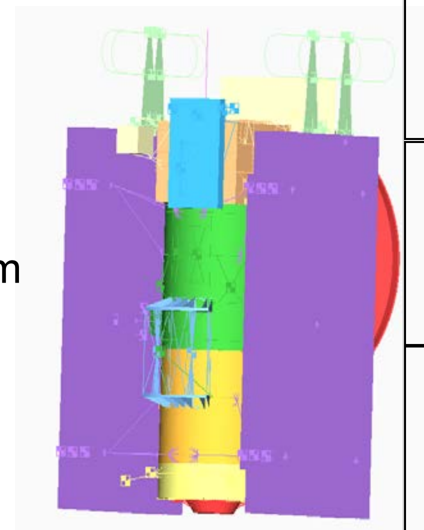
Vibration Environments

- The random vib environments have been derived for assemblies and subsystems at their interfaces.
  - Using force and MMAC response-limited vibration and acoustic input from Delta IV H and SLS B1B.
- The vibration levels are defined by the S/C zones.
  - The vib levels depend on the location.
  - The max Qual/PF level is 27.5 g_{rms} for ICEMAG sensors.
- All assemblies or subsystems require a random vibration test.
  - Except for SA and HGA (covered by acoustics).
- A spacecraft PF random vib test will also be performed.



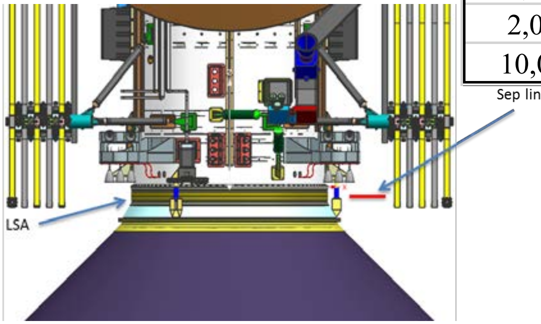
- Zone1 – Lower PM Cone
- Zone2 – Lower PM Skirt
- Zone3 – Lower PM Cylinder
- Zone4 – Upper PM Cylinder
- Zone5 – PM Flanges
- Zone6 – Fuel & O2 Tanks
- Zone7 – Solar Array
- Zone8 – HGA (Reflector)
- Zone9 – Vault Interior
- Zone10 – Vault Cantilever
- Zone11 – Nadir Platform
- Zone12 – Reason Antennas
- Zone13 - IceMagBoom

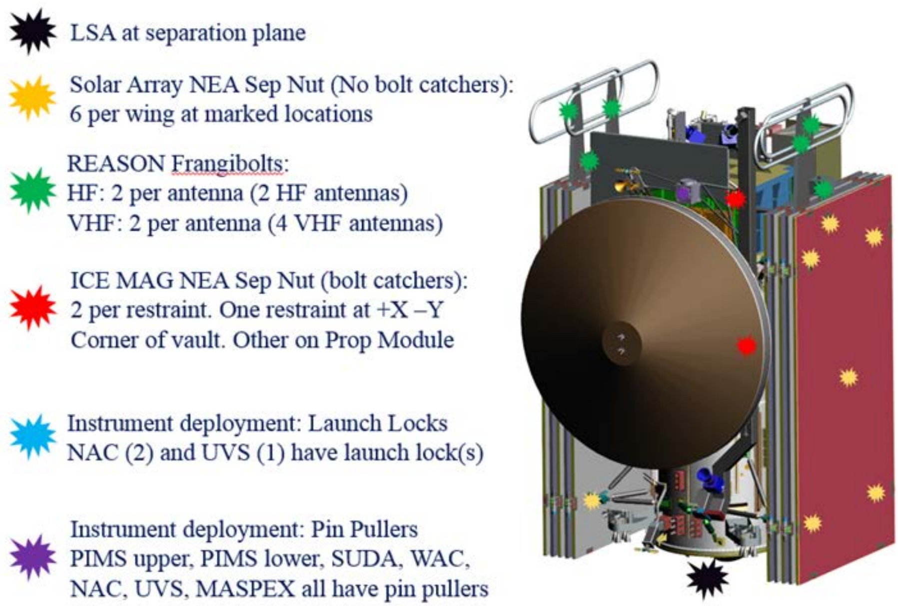
Zone	Component	Frequency (Hz)	FA (Acceleration Spectral Density or Slope) (1 min/Axis)	Qual/PF (Acceleration Spectral Density or Slope) (2 min/1 min/Axis)
1*	WU	20 - 40	+6 dB/oct	+6 dB/oct
	(Reaction	40 - 60	0.04 g^2/Hz	0.08 g^2/Hz
	Wheels)	60 - 80	+36 dB/oct	+36 dB/oct
		80 - 110	1.25 g^2/Hz	2.5 g^2/Hz
		110 - 200	-17.3 dB/oct	-17.3 dB/oct
		200 - 500	0.04 g^2/Hz	0.08 g^2/Hz
		500 - 2000	-3 dB/oct	-3 dB/oct
		Overall g_{rms}:	10.6g	15g
9-2*	PCDA Box	20 - 75	+9.5 dB/oct	+9.5 dB/oct
	REU Box	75 - 100	0.65 g^2/Hz	1.3 g^2/Hz
	SUDA Box	100 - 125	+5.8 dB/oct	+5.8 dB/oct
		125 - 170	1.0 g^2/Hz	2.0 g^2/Hz
		170 - 250	-25.1 dB/oct	-25.1 dB/oct
		250 - 500	0.04 g^2/Hz	0.08 g^2/Hz
		500 - 2000	-3 dB/oct	-3 dB/oct
		Overall g_{rms}:	12.5g	17.5g
12-1*	REASON VHF	20 - 30	+20.1 dB/oct	+20.1 dB/oct
	Antennas	30 - 50	0.75 g^2/Hz	1.5 g^2/Hz
		50 - 60	+11.4 dB/oct	+11.4 dB/oct
		60 - 90	1.5 g^2/Hz	3 g^2/Hz
		90 - 110	-26.2 dB/oct	-26.2 dB/oct
		110 - 200	0.5 g^2/Hz	1.0 g^2/Hz
		200 - 2000	-5.4 dB/oct	-5.4 dB/oct
		Overall g_{rms}:	16.6g	23.3g
12-2*	REASON HF	20 - 32	+28.1 dB/oct	+28.1 dB/oct
	Antennas	32 - 48	4 g^2/Hz	8 g^2/Hz
		48 - 70	-36.7 dB/oct	-36.7 dB/oct
		70 - 500	0.04 g^2/Hz	0.08 g^2/Hz
		500 - 2000	-3 dB/oct	-3 dB/oct
		Overall g_{rms}:	11.8g	16.6g
13	ICEMAG	20 – 45	+21 dB/oct	+21 dB/oct
	Sensors	45 – 65	6.0 g^2/Hz	12.0 g^2/Hz
		65 – 75	-29 dB/oct	-29 dB/oct
		75 – 100	1.5 g^2/Hz	3.0 g^2/Hz
		100 - 500	-6.5 dB/oct	-6.5 dB/oct
		500	0.04	0.08
		500 - 2000	-3 dB/oct	-3 dB/oct
		Overall g_{rms}:	19.4g	27.5g

Shock Environments

- The shock environment comes from 2 sources:
  1. S/C separation from launch vehicle.
     - Pyro-device: MEFL = 5000g peak SRS.
  2. S/C component release and deployment mechanisms.
     - List of shock sources:
       - Solar array Non-Explosive Actuators (NEA) Sep Nuts.
       - ICEMAG boom launch restraints release NEA Sep Nuts.
       - REASON antennas Frangibolts.
       - Instrument deployment Pin Pullers.
       - Instrument deployment launch locks.
- Derived shock levels for each equipment throughout S/C.
  - Assembly Qual/PF level: 775 g to 2800 g peak.
  - Based on the intensity, distance, and number of structural joints from the shock sources.
- Shock qualification testing is required for all equipment containing shock-sensitive components.
- After integration, the S/C will undergo a device firing test.

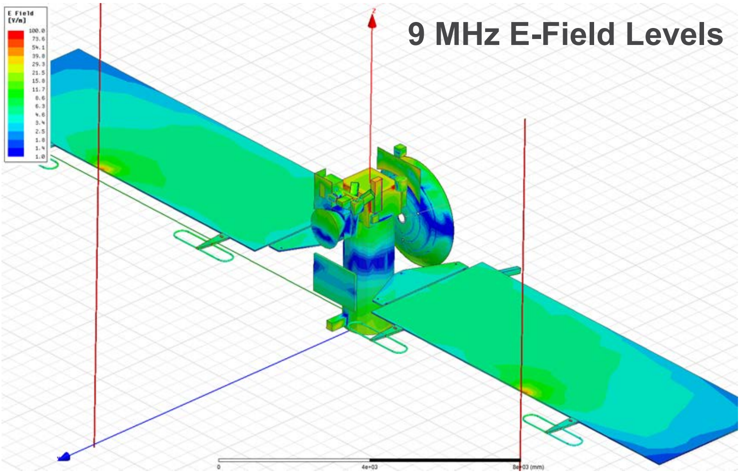
Frequency Hz	MEFL SRS (Q=10)
100	100 g
1,000	2,400 g
2,000	5,000 g
10,000	5,000 g

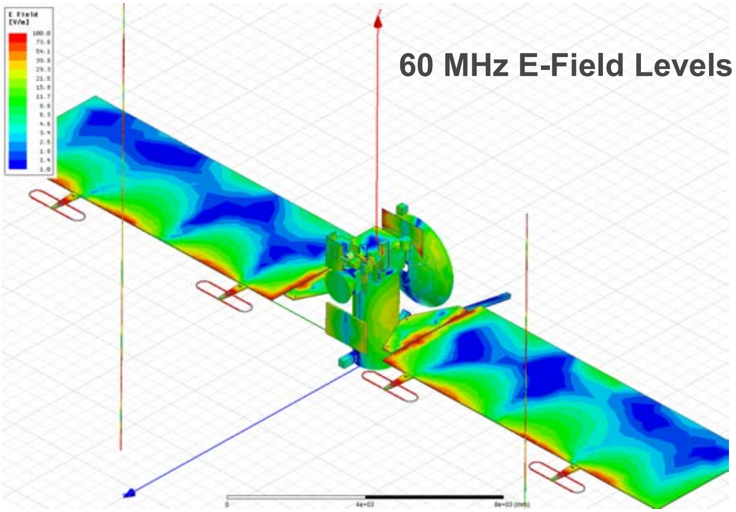




EMC/EMI Driving Requirements

- The radiated emission (RE102) requirements are primarily driven by the REASON instrument.
  - Operating frequencies: 9 MHz and 60 MHz.
  - Any electronic equipment with clocks or oscillators having harmonics at 9 MHz or the 60 MHz, could interfere with the REASON instrument.
  - This requires severely limiting the RE102 radiated emission at these frequencies.
- The radiated susceptibility (RS103) requirements are also influenced by the REASON transmitters.
  - All S/C equipment must function within spec while exposed to the radiated E-fields transmitted by the REASON HF and VHF antennas.
- Performed simulation of the REASON radiated E-fields at 9 MHz and 60 MHz.
  - Identifies the regions with the high field levels.
  - Used for determining the radiated susceptibility, RS103, levels for each location.
- Generated an EMC Control Plan provide guidelines for designing EMC compliant hardware.
- All equipment will be EMC tested to demonstrate compliance with the RE and RS requirements.





Magnetic Emission Requirements

- The magnetic emission requirements are driven by the sensitive ICEMAG and PIMS instruments.
  - ICEMAG: 5 nT at the outboard magnetometer sensor
  - PIMS: 250 nT at the PIMS sensor and extending out to 110 degree FOV.
- Limit the total S/C magnetic field contributions.
- Set up a Magnetics Model to simulate the magnetic fields throughout the S/C.
  - Identified >150 magnetic moments of concern.
  - Inputted into the model.
  - Predicted the magnetic field at different locations of the S/C.
  - Use results to specify the magnetic moment and magnetic field allocations for each equipment.
- Generated an Magnetics Control Plan provide guidelines for designing magnetically compliant hardware.
- All equipment will be magnetically-characterized before delivery into the S/C integration process.
  - Non-compliant equipment will be degaussed, as necessary.

PIMS

PIMS Upper

Total B field at PIMS Upper (nT) in Europa SC coordinates			
Bx	By	Bz	Brss
-44.34	59.27	-108.29	131.17

PIMS Lower

Total B field at PIMS Lower (nT) in Europa SC coordinates			
Bx	By	Bz	Brss
-6.82	-13.16	232.25	232.72

ICEMAG

ICEMAG SVH1

Total B field at ICEMAG SVH1 magnetometer (nT) in Europa SC coordinates			
Bx	By	Bz	Brss
-1.71	3.27	2.56	4.49

ICEMAG SVH2

Total B field at ICEMAG SVH2 magnetometer (nT) in Europa SC coordinates			
Bx	By	Bz	Brss
-4.00	5.36	6.85	9.57

ICEMAG FG1

Total B field at ICEMAG FG1 magnetometer (nT) in Europa SC coordinates			
Bx	By	Bz	Brss
-7.25	8.52	14.40	18.24

ICEMAG FG2

Total B field at ICEMAG FG2 magnetometer (nT) in Europa SC coordinates			
Bx	By	Bz	Brss
-6.89	20.79	31.91	38.70

Environmental Verification

Assembly/Subsystem/Instrument

- **Dynamics tests**
  - Random vibration
  - Shock
  - Acoustic noise (selected - large area/mass)
  - Structural Loads (structural elements)
  - Microphonics (susceptible h/w)
- **Thermal tests**
  - Thermal vacuum (all hardware)
  - Thermal cycling life qual (selected – eg. solar array)
- **EMC/EMI/Magnetic tests**
  - Conducted susceptibility/emission
  - Radiated susceptibility/emission
  - Grounding & isolation
  - Multipacting/ionization breakdown/corona (high voltage h/w)
- **Natural space**
  - Radiation (TID/DDD/SEE/iESD) tests and analyses
  - Venting (pressurization & depressurization) analysis
  - Micrometeoroid test (for selected vulnerable items)

Spacecraft

- **Dynamics tests**
  - S/C Modal test
  - Random vibration
  - Acoustic noise
  - Pyro firing (LV separation & deployment)
- **Thermal tests**
  - Thermal vacuum (w/ thermal balance - critical h/w at FA limits during functional)
- **EMC/EMI/Magnetic tests**
  - Radiated emission
  - Radiated susceptibility
  - Self compatibility (subsystems/Instruments)
  - Magnetic cleanliness
- **Environmental analyses**
  - Orbital debris analysis
  - Micrometeoroid analysis (prob. of survival & shielding effectiveness)

Conclusions

- Identified a set of driving environmental requirements for the Europa Clipper Mission.
  - The environmental requirements will be baselined by Project PDR (Preliminary Design Review) in August 2018.
- Defined a rigorous environmental verification program.
  - Environmental testing and analyses will accelerate immediately after the Project PDR.

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